SWMM REDEVELOPMENT PROJECT PLAN

Version 5

Water Supply and Water Resources Division

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I. Introduction

The Stormwater Management Model(SWMM) is a dynamic rainfall-runoff simulation model, used for single-event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The model is segmented into four "computational blocks" and "five service blocks". Within the Runoff Block, hydrologic computations include rainfall-generated runoff and a water balance based on rainfall, snowmelt, soil infiltration, depression storage, evaporation, and groundwater flow. Flow and storage routing can be accomplished in the Runoff, Transport, and Extran Blocks, with additional storage routing in the Storage/Treatment (S/T) Block. The Extran Block is very widely used because of its ability to solve the complete dynamic equations of motion (Saint-Venant equations) therefore it can simulate backwater, surcharging, pressure flow, looped connections and other hydraulic complexities. Nonpoint source water quality may be generated in the Runoff Block and routed within the Runoff, Transport, and S/T Blocks, but not within the Extran Block. Dry-weather flow and other ancillary quality functions may be simulated in various blocks. The five service blocks (Rain, Temp, Statistics, Combine, and Graph) provide for input of long-term rainfall and other necessary time series data as well as statistical analysis of the output and manipulation interface files for transfer of intermediate hydrographs and pollutographs from one block to the other.

SWMM is one of the most successful models produced by the EPA for the water environment. Originally developed in 1969-71, it has withstood the test of time and continues to be widely used throughout the world for analysis of quantity and quality problems related to stormwater runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well. From 1988 through 1999, the EPA Center for Exposure Assessment Modeling in Athens, Georgia, distributed approximately 3,600 copies of SWMM. The University of Florida distributed roughly 1,000 copies of SWMM in the late 1980's. Third party interfaces for SWMM, such as MIKE-SWMM, PC_SWMM, and XP-SWMM, have several thousand users. The number of subscribers to the SWMM Users group listserve on the Internet is nearly 10,000.

For the management of CSOs for complying with the National CSO Control Policy, many States including New Jersey specify that SWMM or its equivalent shall be used in the modeling of combined sewer systems and development of CSO control options and designs. SWMM is considered by the engineering community in the U.S. to be the de facto "model" for comprehensive hydrologic/hydraulic/water quality analyses associated with urban sewer systems. It has enjoyed a highly useful life of over 30 years.   As a consequence, the interest in and desire for a better SWMM have not faded with time. Instead, the needs and wishes of the SWMM user community increases as computer technology improves and the public's expectations of a cleaner environment rise.

This project plan describes the objectives, rationale, and approach for modernizing SWMM. It is intended to be a work-in-progress, which can be modified as feedback is received from outside project reviewers as well as from the project team itself. This current version of the plan incorporates suggestions made by the project's Technical Design Panel at their September 2001 meeting.

II. Objectives

The goal of this project is to help meet the needs of EPA’s clients for improved computational tools for managing urban runoff and wet weather water quality problems. We intend to produce a new version of SWMM that incorporates modern software engineering methods as well as updated computational techniques. The specific objectives of this project are:

- To revise the architecture of the SWMM computational engine, using object oriented programming (OOP) techniques, to enhance the ability of the model to be maintained, upgraded, and interfaced with other software.

- To provide a rudimentary graphical user interface (GUI) to the engine to improve the usability of the model.

- To remove obsolete features, improve key computational aspects, and add new computational capabilities to the model where warranted.

- To develop guidelines on how SWMM can be used to model more recently developed Best Management Practices (BMP) for runoff control.

The end products from this project will consist of the following:

- A newly coded version of the SWMM computational engine that can be run either as a stand-alone application or as a Dynamic Link Library (DLL) of functions that can be called from other applications such as third party vendors of SWMM.

- A GUI shell program that will run under Windows, access the SWMM engine through DLL calls, and include a context-sensitive, on-line Help system.

- Full documentation in the form of a Users Manual, a Programmer’s Manual, and a Reference Manual.

- A manual on Modeling BMPs with SWMM that will illustrate how SWMM can be used to model various types of BMP/LID options.

III. Rationale

This work is being undertaken for the following reasons:

- The current SWMM code consists of almost 50,000 lines of FORTRAN code that have been patched together over some 30 years with a very uneven level of commenting and documentation. There is just a handful of people in the world who can confidently make revisions to the code without fearing that major bugs will be introduced in the process. The code needs to be restructured, preferably in an object oriented manner, so as to become more manageable and understandable and maintain SWMM's accessibility to a new generation of modelers.

- Over its development it appears that new features were only added to SWMM but obsolete ones were never removed. Examples of the latter include the Graph module, the use of Dust and Dirt as a measure of runoff quality, and the capability to read NWS rainfall data in obsolete formats. The obsolete and unessential features should be identified and removed to make the code more streamlined and maintainable.

- The input file format used to describe a drainage area and control a simulation using SWMM is antiquated and unwieldy. The requirements it imposes on users to specify how the various modules in SWMM should be linked together through scratch files are the source of frequent input errors. The numerous "card codes" used to identify blocks of related data are non-intuitive and require constant references be made to the Users Manual. There is no facility to interactively view selected portions of the voluminous output produced by SWMM in a visually intuitive way. A graphical user interface is sorely needed to improve the way that SWMM can be utilized most effectively.

- The Transport and Extran blocks, which use different computational methods to route flow through the same physical set of conduits, are not data compatible with each other. Users must prepare two sets of very similar data if they want to run both the kinematic wave (Transport) and the dynamic wave (Extran) routing methods for the same set of conduits.

- The Extran module does not include routing of water quality constituents. This precludes the use of this powerful tool in water quality studies. Even in the Transport block, the method used to route contaminants is very simplistic and could be replaced by more accurate methods developed for water quality modeling in river networks and drinking water distribution systems.

- SWMM has limited ability to simulate Real Time Control (RTC) through the remote manipulation of control structures (e.g., regulators, gates, orifices, weirs, pumps) within a sewer system, based on conditions (e.g., stage, flow rates, water quality, sediment depth) in order to optimize utilization of available in-system storage and operation. For SWMM to improve its RTC capability, the numerical stability and computational efficiency of its Extran module needs to be improved as does its user interface used to define control rules.

- EPA currently has no permanent staff who are familiar with the inner workings of SWMM and can provide technical expertise and support for the model. SWMM has essentially become an orphan within the agency. This project will provide an opportunity for EPA to once again assume a hands-on involvement with SWMM and develop authoritative expertise and leadership in this area.

IV. Participants

This project will be a joint development effort between EPA-NRMRL's Water Supply and Water Resources Division and Camp Dresser and McKee Inc. (CDM). CDM's participation will be through a CRADA (Cooperative Research and Development Agreement) between itself and the Agency. They will share technical expertise and collaborate with EPA engineers and scientists in the following areas:

- supply technical and programming expertise on the current SWMM code
- suggest needed revisions and updates to the code
- update and improve the Extran (full dynamic flow routing) portion of SWMM
- develop data file converters for previous versions of SWMM input and output
- help implement quality assurance testing
- assist in the preparation of program documentation.

In addition to CDM, the consulting services of Dr. Wayne Huber of Oregon State University, one of the original developers and a long-time maintainer of the SWMM code, have been acquired under a small purchase order contract. Dr. Huber will assist the project team in understanding the legacy FORTRAN code contained in the current SWMM program and will be repsonsible for preparing the Reference Manual that will be part of the project's set of documentation.

Three other groups will be invited to participate in this project. One will be a Technical Design Panel made up of modeling experts who will suggest and critique the form, function, and technical direction that the project will follow. This panel has already been assembled and had its first meeting on September 21-22, 2001. The members of this panel include the following:

Anthony Donigian	President, AQUA TERRA Consultants
Randall Greer	Environmental Engineer, Delaware DNRE and ASIWPCA
James Heaney	Professor, University of Colorado
Wayne Huber	Professor, Oregon State University
Brian Marengo	Philadelphia Water Department
Larry Roesner	Professor, Colorado State University
Ben Urbonas	Denver Urban Drainage & Flood Control District

A second group will comprise a Technical Review Panel which will participate in formal quality assurance testing activities over the duration of the project. The third group is the current SWMM user community, as well as vendors of SWMM pre/post-processor software. This group will be kept informed of the intent and progress of the project and be asked to provide a more informal type of feedback as the project unfolds.

Figure 1 illustrates how the various project participants will interact with one another. EPA and CDM will propose a set of program specifications that will map out the functionality to be included in the updated version of SWMM. The Technical Design Panel will review these proposals and make suggestions and recommendations at an initial project meeting. After the Project Specifications are agreed on, a project Quality Assurance Plan will be published. EPA and CDM will use these as guidelines to produce a version of the model that is suitable for testing. CDM will focus on the Extran portion of the code, while EPA will address the other portions of the computational engine as well as the graphical user interface (GUI). During this time there will be a free flow of information between the EPA and CDM project members. After a set of internal quality assurance checks are completed, a beta-test version of the updated SWMM will be made available to the Technical Review Panel and to the SWMM user community for feedback, testing, and comment.

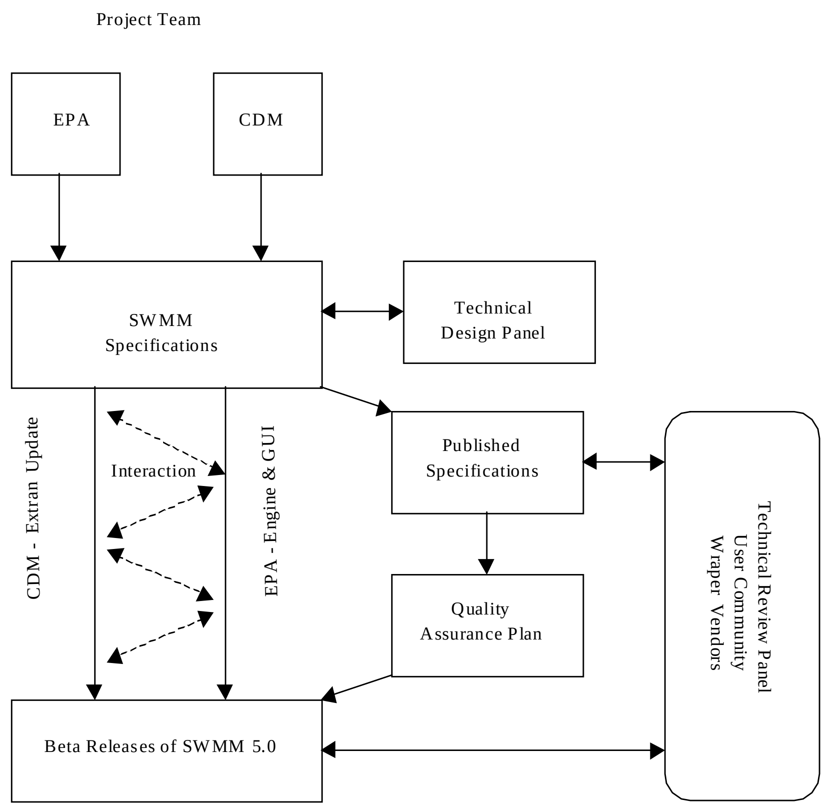

Figure 1. Interactions Among the Project's Participants

V. Approach

The work envisioned for this project can be divided into nine task areas as follows:

1. Re-examine SWMM's functionality
2. Re-write SWMM's computational engine
3. Adapt an existing graphical user interface for use with SWMM
4. Update and add to SWMM's computational algorithms
5. Develop standard formats and procedures for data transfer
6. Develop converters for input/output from previous versions of SWMM
7. Identify how state-of-the-art BMP/LID modeling can be incorporated into SWMM
8. Prepare program documentation
9. Conduct quality assurance testing

<u>1. SWWM's Functionality</u>

Since this project affords the opportunity to rebuild SWMM from the ground up, it seemed worthwhile to ask which computational features currently contained in SWMM could be eliminated, which should be retained in their current form, which are in need of updating, and which additional features should be added. Based on input received from the project's Technical Design Panel, Table 1 lists the computational functionality we have decided to include in the initial re-write of SWMM. Features being dropped because they are based on obsolete data or are seldom (or incorrectly) used include:

- dry weather flow regression equations
- support for obsolete rain file formats
- nonlinear reservoir routing through gutters and pipes in Runoff
- drain infiltration calculations in Transport
- backwater elements in Transport
- special treatment of catchbasins
- dust and dirt as a measure of pollutant buildup.

New features that are prime candidates for inclusion in future versions of the software are:

- SCS curve number infiltration
- soil moisture accounting model for groundwater
- energy balance model for snowmelt
- implicit dynamic wave flow routing
- Lagrangian water quality transport model
- bed/suspended load sediment transport model
- interactive real-time control of sewer flow routing.

Table 1. Computational Features to be Contained in the New SWMM

Rainfall Data
- User-Supplied Time Series
- Current NWS and AES File Formats
- Event Statistics (SYNOP)

Infiltration
- Horton
- Green Ampt

Groundwater
- Two-Zone Model

Snowmelt
- Degree Day Model

Evaporation Data
- User-Supplied Monthly Averages
- NWS Meteorological Files

Temperature Data
- NWS Meteorological Files

Overland Flow
- Nonlinear Reservoir Model

Drainage System Elements
- Pipes and Channels
- Pumps, Orifices, and Weirs
- Flow Dividers
- Storage Units

Cross-Sections
- Simple Geometries
- Non-Standard Geometries
- Natural Channels and Bridges

Flow Routing
- Kinematic Wave
- Dynamic Wave

Pollutant Loading
- Buildup and Washoff
- Erosion
- Dry Weather Flow
- Street Cleaning

Pollutant Routing
- CSTR Model

Sediment Transport
- Shields Scour/Deposition

Storage/Treatment
- Generalized Storage Unit Reactor Model

Real Time Control
- Level Control
- Timer Control
- Rule-based Control

2. The Computational Engine

The computational engine which implements the modeling functionality embedded in SWMM will be re-written in C++ using an object oriented approach. The choice of this approach is justified for the following reasons:

- Over the past decade, object oriented programming has replaced procedural programming (in which SWMM was originally developed) throughout the software industry. The embedding of both data and functions within discrete objects is known to make for more modular, maintainable, and bug-free code. These advantages become even more apparent when the scope of the project grows in size to reach the level of SWMM.

- The physical elements contained within a drainage area, such as land areas, land uses, collection channels, main conduits, pumps, regulators, etc. naturally lend themselves to an object oriented representation. Consider a land area (or *Subcatchment*) object for example. In addition to its physical properties, such as area, slope, percent impervious, etc. it can include a reference to a *Raingage* object from which it would obtain rainfall in a given time period using a method with a name like *getRainfall*. Likewise, it would include a reference to an *Infiltration* object, from which an infiltration rate would be computed in a given time period using a call to *getInfiltration*. Both of these functions would be used in the object's *getRunoff* method. Because of the encapsulation and inheritance features of object oriented programming, the *Subcatchment* object doesn't know (and doesn't care) about the details of the *getRainfall* and *getInfiltration* methods. These are handled by the respective *Raingage* and *Infiltration* objects, and will be different depending on whether the *Raingage* object's subclass is a user-supplied time series or a National Weather Service data file, or if the *Infiltration* object's subclass is Horton or Green-Ampt. In fact, a new type of infiltration model, such as the SCS Curve Number approach, could be added as a sub-class to *Infiltration* without having to make any modifications to the *Subcatchment* class.

- Although there are a number of programming languages that support object oriented development (such as C++, Object Pascal, Java, and Smalltalk) C++ is preferred for its computational efficiency and widespread utilization and availability. There are a number of C++ compilers (both commercial and public domain) available for the MS Windows, Linux, and Unix operating systems. This language now accounts for the vast majority of software written for both the PC and Unix-workstation environments, and is not likely to become obsolete as has FORTRAN. The modern day C++ compilers are highly optimized and the efficiency of the machine code they produce is comparable to that of FORTRAN compilers. Using C++ will make the SWMM code more accessible to a wider audience of programmers for adaptation and modification in specialized applications or research studies.

The SWMM engine will be delivered in two formats. One will be a stand-alone executable that receives input from a text file and writes output to a text file and/or binary output file. The other will be a library of callable functions that can be accessed by other software, such as the SWMM Graphical User Interface module discussed below. For the Windows operating system, the library will be compiled as a DLL (Dynamic Link Library). This follows the same approach used by the highly successful EPANET model, which analyzes hydraulic and water quality behavior in drinking water distribution systems (Rossman, 2000). In EPANET only one line of code needs to be changed to compile the program as a DLL as opposed to a stand-alone executable.

Construction of the engine will utilize the Rapid Prototyping Method of software development and have much in common with what has become known as the Extreme Programming approach (i.e., simplicity, evolutionary development, using formal design and diagrams only when necessary) (Fowler, 2001). An initial working prototype of the new SWMM engine and GUI will be constructed at the outset of the project, to provide a structure upon which the rest of the project can build. The initial prototype will contain a core sub-set of the functionality listed in Table 1. An object-oriented structure for most of the core SWMM engine has already been developed and is described in the Appendix.

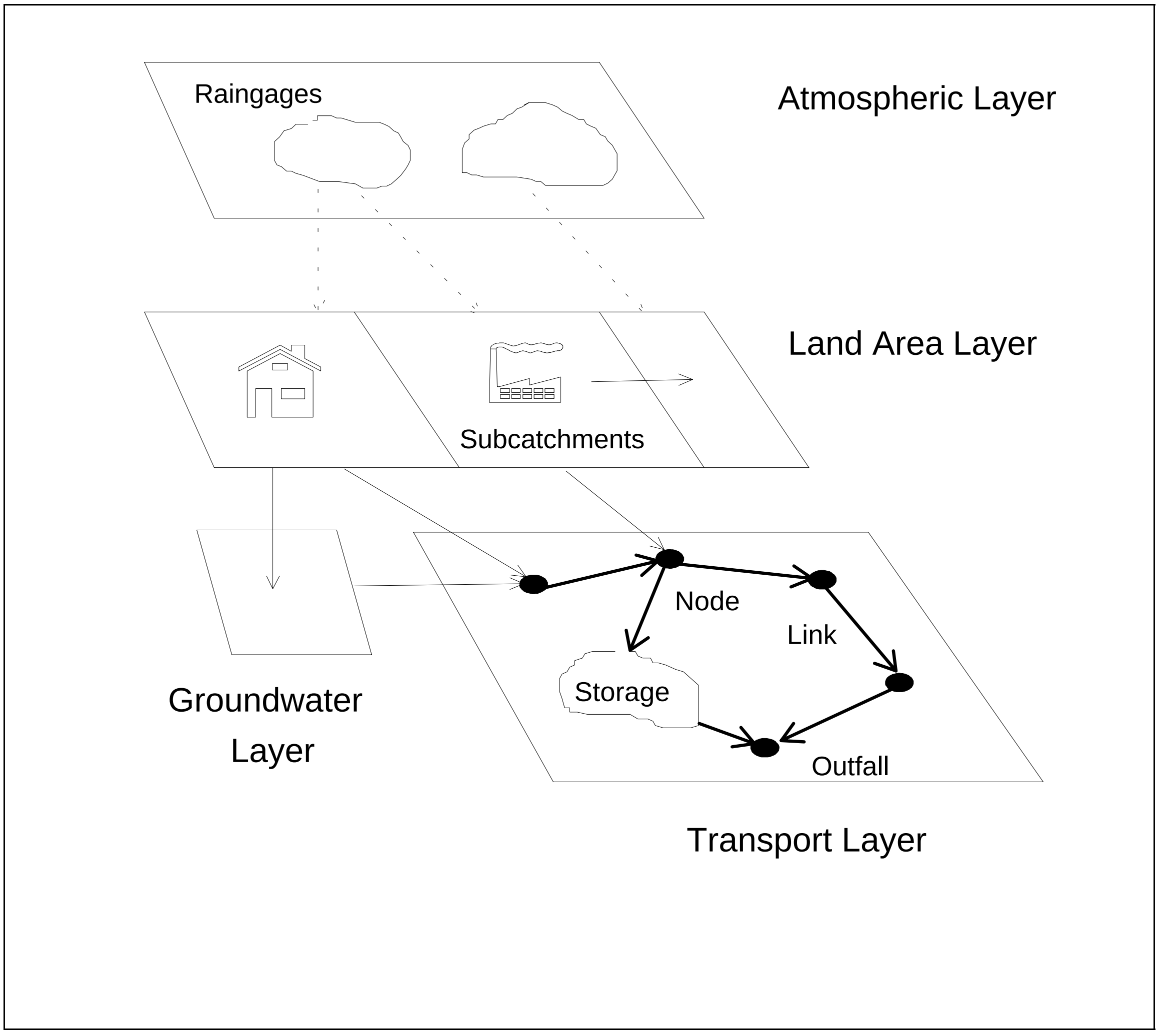

Figure 2. SWMM's Conceptualization of a Drainage Area

The basic way in which SWMM has traditionally conceptualized a drainage area and represented its various physical components will essentially remain the same. Figure 2 depicts this conceptualization as a flow of water and constituents between several different compartments. These compartments include:

- The Atmosphere from which precipitation falls onto the land area compartment.

- The Land Area compartment, which receives inflow from the Atmospheric compartment in the form of rain and possibly runoff from other land areas; it sends outflow in the form of infiltration to the Groundwater compartment and also as runoff to the Transport compartment, as well as to other subcatchments in the Land Area compartment.

- The Groundwater compartment which receives infiltration from the Land Area compartment and transfers outflow to the Transport compartment.

- The Transport compartment containing the network of channles, conduits, pumps, and regulators that transport water to outfalls or to treatment works.

3. Graphical User Interface

The SWMM graphical user interface will be ported over from the previously developed EPANET user interface. We estimate that about 80% of the existing code can be used with either no or only minor modification. Without this high degree of re-usability it probably would not be feasible to include GUI development within this project.

A flavor of what the GUI will look like is shown in Figure 3. It allows the user to draw a node-link representation of the drainage network on a scalable map, with the option of inserting a background reference map. Point and click actions can be used to add, delete, re-position, and edit specific objects depicted on the map. Color coding of the map's features are used to represent the values of user-selected design parameters or computed output. Additional views of computed results are available in the form of graphs (time series plots, profile plots, and frequency plots) and user-defined tables.

Retrofitting the EPANET GUI to meet the specific needs of SWMM will proceed in parallel with the development of the computational engine, since data definitions and file formats have to remain synchronized between the two modules. The GUI also presents a simpler way to perform testing and debugging of the engine than would the command line interface. The GUI will be subjected to the same iterative review procedures as will the engine, with the understanding that its functionality will not grow beyond what is already included in EPANET.

An added requirement of developing a GUI for SWMM is the inclusion of a context-sensitive Help facility. To the extent feasible, the addition of this capability will utilize the HTML Users Manual that will be written as part of this project (see below). This will help reduce the effort required to write a separate Help system for the GUI.

4. Computational Methods

In conjunction with the need to evaluate the functionality to be included in the updated SWMM there is also a need to evaluate which computational methods should be improved or replaced. EPA will explore making the following computational enhancements in future versions of the SWMM software:

- The current method of routing water quality constituents (which is available only with the Transport module) could be improved by adopting one of the Lagrangian methods utilized for modeling advective transport in rivers (Jobson and Schoellhamer, 1987) and water distribution pipe networks (Rossman and Boulos, 1996). Since the Extran module will become integrated with the former Transport module, water quality routing will also be available when fully dynamic flow routing is utilized.

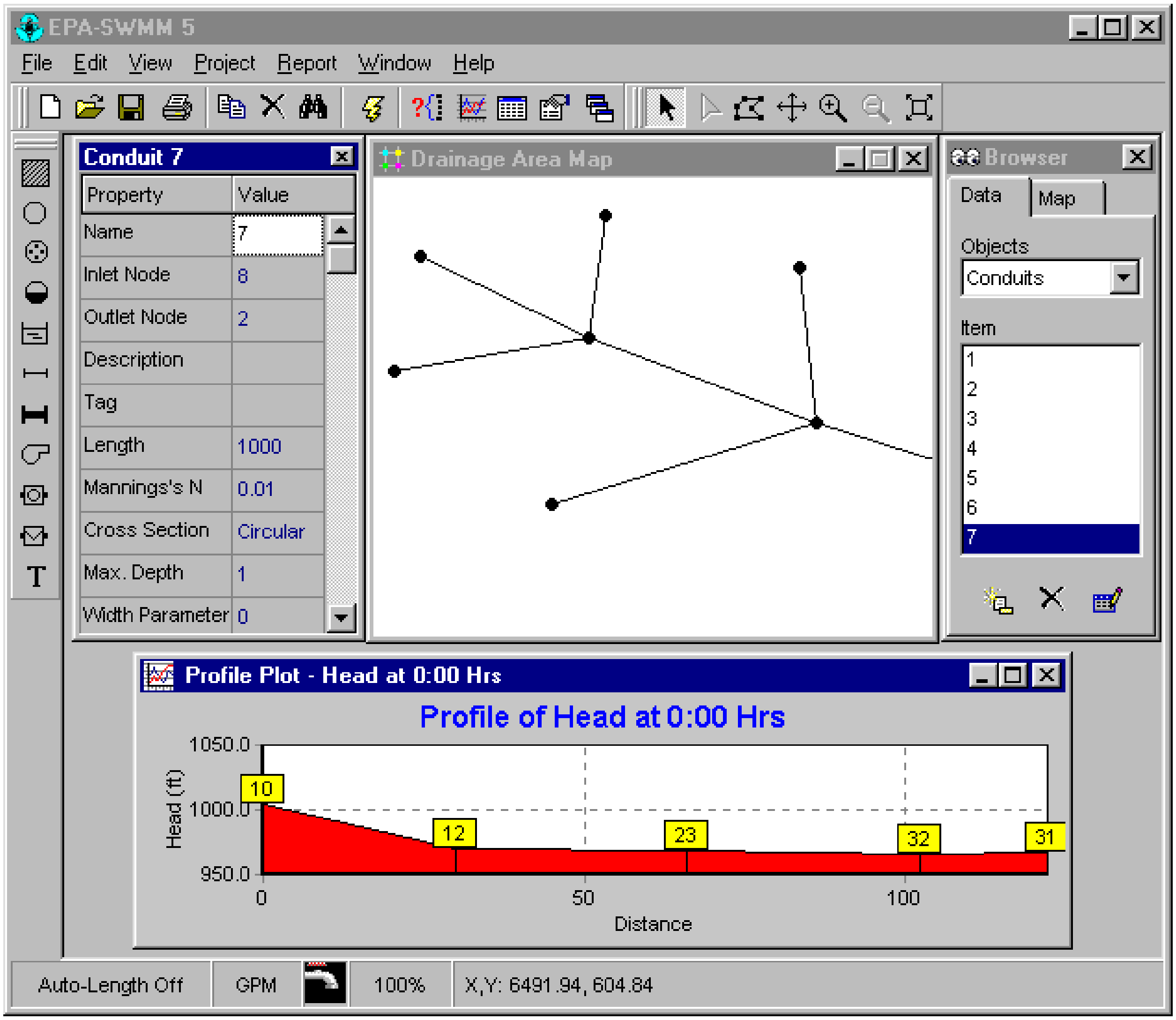

Figure 3. Screen Shot of the New SWMM Graphical User Interface

- CDM intends to modify the explicit solution method used for dynamic flow routing in Extran to make it more efficient and robust. In addition, EPA will explore the efficacy of adding an implicit flow routing method as another alternative. Various implementations of the 4-point implicit (Preissman Box) scheme will be evaluated. These include the Extended Relaxation Technique currently employed in the NWS FLDWAV model (Lewis et al., 1996), the double sweep, recursive method of Choi and Molinas (1993), and the SUPERLINK model used in the SEWERCAT program (Ji, 1998). Other approaches, which solve the Saint-Venant equations in conservative form, include second order relaxation schemes (Aral et al., 1999) and finite volume methods (Toro, 1997).

- The sediment transport sub-model employed in SWMM will be re-visited. The use of other simplified equations for determining when scour or deposition occurs will be considered (see Zug et al., 1998 for example). More complex models, that provide refined estimates of bed shear stress and explicitly model bed transport will also be examined (Mark, 1992). An evaluation will be made to determine if an enhanced sediment model is worth including into the new SWMM based on such criteria as model reliability, robustness, and ease of implementation.

- We will investigate the possible advantages of replacing the current degree-day model used in SWMM's snowmelt computation with the more physically correct heat budget model as is used in the HSPF model for example (Johanson et al., 1984).

5. Data Standards and Interfaces

The use of industry-standard data formats for generating input and output data for SWMM's computational engine would facilitate its linkage with third party software, such as Geographical Information Systems (GIS), computer aided drawing (CAD) software, statistical packages, and ODBC-compliant database systems (e.g., Access, Oracle, etc.). Data format standardization would also assist in sharing of data with other government agency databases.

Examples of alternative data standards include:

- ODBC-compliant database formats, such as Microsoft Access or dBase IV.

- the HEC-DSS file format (HEC, 1994) used in HEC's HMS (Hydrological Modeling System) software for storing time series data

- the USGS-WDM file format (Flynn et al., 1995) used by USGS and EPA for storing time series data

- the FGDC Utility Standards (Federal Geographic Data Committee, 2000) developed by the Federal Geographic Data Committee for representing geo-referenced infrastructure objects

- the ArcGIS Water Facilities and Hydro data models developed by ESRI (ESRI, 2000) that allow seamless integration of numerical modeling within the ArcGIS framework

- XML (Extensible Markup Language) format (World Wide Web Consortium, 2000) which is a general method for storing hierarchical-structured data that is highly transportable between computing platforms and is finding widespread acceptance in distributed computing and web-based applications.

Each of these formats will be evaluated with respect to how they might be used with SWMM input and output data and what advantages they would bring to the overall SWMM package. Based on the results of this evaluation, one or more of these formats will be utilized by the SWMM engine or by its graphical user interface.

Both EPA and CDM will collaborate on this portion of the project.

6. Input/Output Data Converters

A converter program will be written, as a separate piece of software, that will read any SWMM data file after version 3.3 and translate it into a format that can be read by the new version of SWMM. CDM will take the lead on this portion of the project.

7. BMP/LID Modeling

SWMM already has a few processes (overland runoff, sewer routing, soil infiltration, and storage) that can be used to conceptualize best management practices (BMPs) and low-impact development (LID). However, a fresh look at the processes in the existing SWMM is necessary so that new discovery and development in GIS technology (spatial modeling), soil infiltration, and physical, chemical, and biological processes associated with upland alternatives for stormwater management in the scale of a residential parcel can be implemented. An extramural research project is expected to begin in March, 2001 to look into this matter. The Contractor was asked to define the modeling concepts and mathematical formulations for use in improving SWMM for BMP/LID assessment. The following areas will be addressed:

- Spatial resolution to allow application of micro-management of flows in a residential lot.
- Overland flow movement in pervious and impervious surfaces within a residential lot and from lots to street gutters, swales, buffer strips, channels, and sewers.
- Subsurface flow movement of rainwater infiltration through the unsaturated (aeration) zone and interaction of surface and ground waters.
- Routing and attenuation of pollutants in overland and subsurface flow movement considering subsurface adsorption, absorption, and dispersion processes.
- Routing of flows and pollutants from lots to swales/street gutters/inlets/sewers.

Based on these activities, a BMP/LID Modeling document will be written that describes how SWMM can be utilized and perhaps modified to accommodate the newer generation of low impact development and nonstructural BMPs that have been developed.

EPA-Edison will take the lead on this portion of the project.

8. Program Documentation

Three manuals will be produced from this project. One will be a Users Manual that documents the operation of the new version of SWMM. It will describe the capabilities of the program, the data needed to model the various physical entities and processes in a drainage area, and mechanics involved in actually running the program. A short but fairly comprehensive tutorial problem will be included.

The second manual will be a Programmer's Manual. It will provide detailed information on the structure of the code used to program the new SWMM engine and make it easier for third party developers to customize the new SWMM for their own specific needs. (Details of the GUI code will not be included in this manual because of its platform dependence.)

The third manual will be a Reference Manual that will describe the modeling philosophy of SWMM and document the numerical models used to compute runoff, transport, storage, and treatment. This manual will also provide guidance on model setup and selecting parameter values for various types of SWMM applications.

The manuals will be published in HTML format for ready accessibility over the world wide web. In addition, the Users Manual will serve double duty as forming the backbone of the GUI's context-sensitive Help system.

If appropriate, additional, smaller manuals might be prepared to describe specialized aspects of the new SWMM package, such as the data conversion program written by CDM.

EPA, with assistance from CDM and Dr. Huber, will be responsible for writing the documention. In addition, early on in the project EPA will establish a SWMM 5 web site that will chronicle the progress being made on the project, offer links to current versions of SWMM, and to beta versions of the new SWMM, and provide areas for user comment and feedback.

9. Quality Assurance Testing

Quality assurance activities will be carried out principally by CDM and are described in more detail in Section VI of this plan.

VI. Quality Assurance

Because of the long history associated with SWMM and the wide-spread acceptance of its numerical results, it is essential that this project contain a strong quality assurance component so that credibility and reliability of the new version can be maintained. Quality assurance will consist of two main activities:

- oversight, review and guidance provided by a project Technical Review Panel
- rigorous software testing conducted by the project team and outside volunteers.

A Quality Assurance Project Plan (QAPP) will be prepared by EPA as part of this project. The QAPP will be based on relevant agency guidance (USEPA, 1998) and discuss the planning, execution, and QA protocols that are vital to the success of the project. Elements of the plan will include a needs assessment, requirements analysis, design specifications, implementation controls, testing and verification plans, and documentation requirements.

A rigorous protocol for testing the new software will be developed by the project team. It will include the compilation of input test data sets from various sources. Criteria will be developed to determine when a major discrepancy exists between numerical results obtained using the old SWMM and the new SWMM. The source of the discrepancy can then be investigated to determine if it is a legitimate difference due to a modification in a computational procedure or if it is the result of a program bug. CDM will primarily be responsible for designing the software testing protocol, acquiring the test data sets, and assisting EPA in conducting the testing.

Another, more informal source of software testing and evaluation will be solicited through the SWMM list server maintained by Prof. Bill James at the University of Guelph. In this mode of testing, list server members could be asked to evaluate successive versions of the prototypes as they are released, and report back any problems they encounter to the project team. A similar procedure was followed with the testing of version 2 of the EPANET program and was found to be very effective.

VII. Time Line

Figure 4 depicts a time line of the major activities to be undertaken by this project. Total project duration will be approximately 15 months. After 4-6 months time the functionality and structure of the new code should be solidified enough so that work can begin on defining data transfer standards and writing conversion programs. After 8 months time the prototype engine and GUI should be stable enough for quality assurance testing to begin. The BMP/LID modeling portion of the study will need to be coordinated with the current work assignment that WSWRD-Edison has in this area. The time line shows approximately 3 months time at the end of the project duration reserved to absorb any overruns or unforeseen problems.

VIII. Resources

EPA-NRMRL will assign the equivalent of three FTE employees working full time on this project. CDM's contribution will be strictly in-kind and be determined by their management. The only extramural money required for this project is hold two meetings of the project's technical panels and the procurement of Dr. Huber's consulting time. A figure of $85,000 should cover these needs.

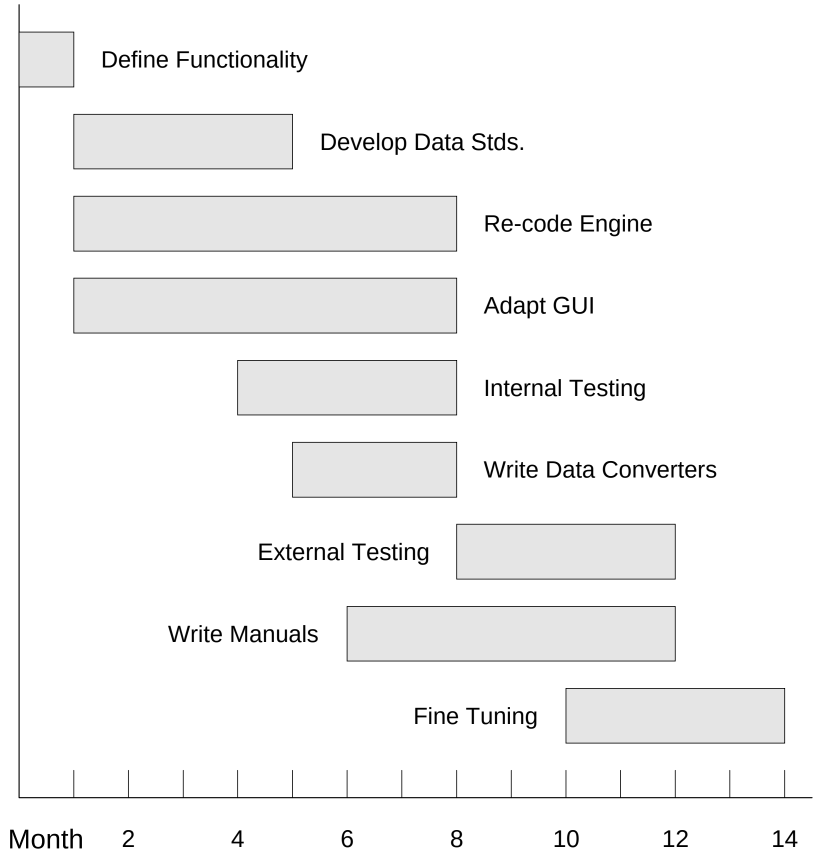

Figure 4. Time Line of the Major Project Activities

IX. References

Aral, M.M., Zhang, Y., and Jin, S. 1998. "Application of relaxation scheme to wave-propagation simulation in open-channel networks", *J. Hydraulic Engineering*, 124:1125-1133.

Bosak, J. 1997. "XML, Java, and the future of the Web", Sun Microsystems, (http://sunsite.unc.edu/pub/sun-info/standards/xml/why/xmlapps.htm)

Choi, G.W. and Molinas, A. 1993. "Simultaneous solution algorithm for channel network modeling", *Water Resources Research*, 29:321-328.

ESRI 2000. *Inside ArcFM Water*, Environmental Systems Research Institute, Redlands, CA.

Flynn, K.M., Hummel, P.R., Lumb, A.M., and Kittle, J.L. Jr. 1995. *Users Manual for ANNIE,* *Version 2*, U.S. Geological Survey Water Resources Investigations, Report 95-4085, Reston, VA.

Fowler, M. 2001. “Design...Dead?”, *Software Development*, April.

Hydrologic Engineering Center. 1994. *HEC-DSS Users Guide and Utility Manuals: Users Manual*, U.S. Army Corps of Engineers, Davis, CA.

Ji, Z. 1998. “General hydrodynamic model for sewer/channel network systems”, *J. Hydraulic Engineering*, 124:307-315.

Jobson, H.E. and Schoellhamer, D.H. 1987. *Users manual for a branched Lagrangian transport model*, US Geological Survey Water Resources Investigations 87-4163.

Johanson, R.C., Imhoff, J.C., Kittle, J.L., and Donigian, A.S. 1984. *Hydrological Simulation Program – FORTRAN (HSPF): Users Manual for Release 8.0*, EPA-600/3-84-066, Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Lewis, J.M., Fread, D.L., and Jin, M. 1996. “An extended relaxation technique for unsteady flows in networks”, *Proc. North American Water and Environment Congress*, ASCE, Reston, VA.

Mark, O. 1992. “A sediment transport model for sewers”, *Wat. Sci. Tech*., 25:141-149.

Rossman, L.A. and Boulos, P.F. 1996. “Numerical methods for modeling water quality in distribution systems: a comparison”, *J. Water Resources Planning and Management*, 122:137-146.

Rossman, L.A. 2000. *EPANET 2 Users Manual*, EPA/600/R-00/057, National Risk Management Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Rumbaugh, James et al. 1991. *Object-oriented Modeling and Design*, Prentice Hall, Englewood Cliffs, NJ.

Toro, E.F. 1997. *Riemann Solvers and Numerical Methods for Fluid Dynamics*, Springer, Heidelberg.

U.S. Environmental Protection Agency, 1998. *EPA Guidance for Quality Assurance Project Plans (EPA QA/G-5)*, EPA/600/R-98/018, Office of Research and Development, Washington, D.C.

World Wide Web Consortium, 2000. “Extensible Markup Language (XML) 1.0 (second edition)”, T. Bray, J. Paoli, C.M. Sperberg, and E. Maler, editors, (www.w3.org).

Zug, M., Bellefleur, D., Phan, L., and Scrivener, O. 1998. “Sediment transport model in sewer networks - a new utilisation of the Velikanov model”, *Wat. Sci. Tech*., 37:187-196.

Appendix. Preliminary Class Structure for SWMM

This appendix develops a preliminary class structure for the updated version of SWMM. Table A.1 lists the major classes along with their purpose, their sub-classes, and their co-classes. (Sub-classes represent the “is-a” relationship while co-classes represent the “has-a” relationship.)

In order to visualize the relationships between the various classes, Object Model Diagrams will be shown for the key classes listed in Table A.1. These diagrams indicate how classes and the objects created from them interrelate to one another. Inheritance relationships, where one class is a subclass of a more general class, are indicated by triangle symbols in the diagram. An aggregation or associative relationship, where one class is composed of objects from another class, is shown by a diamond symbol. Other symbols show how many instances of a given class may relate to a single instance of another class. A single line indicates one related object, a filled circle indicates many, and an open circle indicates zero or more.

Figure A.1 is a diagram showing the relationships between the three main classes of physical objects in the drainage area – Subcatchments, Nodes, and Links. The figure shows that associated with each Subcatchment object is:

- a Raingage object that supplies rainfall data
- an Infiltration object that computes infiltration losses
- a Groundwater object that computes interflow back to the transport network
- a Node object that defines where surface runoff enters the transport network
- a collection of LanduseFactor objects that define which land uses and their pollutant buildup/washoff characteristics are associated with the subcatchment.

It also shows that associated with each Node is a collection of QualInflow objects (which contain time series data on any possible external pollutant loadings) and that there are 5 sub-classes of nodes that can be represented. Each Link object has two nodes associated with it and there are 4 sub-classes. The Conduit sub-class has an Xsection (cross section geometry) object assigned to it which can be one of several different shapes.

While Figure A.1 shows the relationships between physical objects in the drainage system, it does not provide any information on how the computation of runoff and pollutant loads is accomplished. This process is handled by the Project class, whose Object Model Diagram is shown in Figure A.2. It is the main class within SWMM that houses references to all of the data associated with a project as well as the overall flow of the computations. Only a single instance of this class is created for a run. The properties of this class consist of collections (lists) of the physical components (subcatchments, nodes, and links) that comprise the drainage area.

Table A. 1. Classes To Be Used in SWMM

CLASS	PURPOSE	SUB-CLASSES	CO-CLASSES
Project	Contains collections of a project's objects and controls overall flow of computations		Subcatchment Raingage Pollutant Landuse Node Link
Subcatchment	Describes land areas and the runoff process that occurs over them		Raingage LanduseFactor Infiltration Groundwater Node
Raingage	Provides access to rainfall data		RainDataSource
RainDataSource	Stores and retrieves rainfall data	RainTimeSeries RainFile	
LanduseFactor	Assigns land use to a subcatchment		Landuse
Landuse	Describes pollutant buildup and washoff for a particular land use		Pollutant Buildup Washoff
Pollutant	Names a pollutant included in the analysis		
Infiltration	Describes the infiltration process occurring over a subcatchment	Horton GreenAmpt	
Groundwater	Describes groundwater interflow between subcatchment and drainage system		Node
Node	Models a point in the drainage system where drainage conveyances begin, end, or connect to one another	Junction Manhole Outfall Storage	
Link	Models the behavior of a conveyance element that transports flow and constituents through the drainage system	Conduit Pump Orifice Weir	Xsection
Xsection	Represents the geometric properties and flow-area relationships of a conveyance cross section	CircXsect RectXsect Etc.	
InputReader	Reads input data from text file		
Parser	Parses data from lines of input file	ObjectParser PropertyParser	InputReader
RainfallAnalyzer	Collates rainfall data and analyzes their statistics		
RunoffAnalyzer	Computes runoff from each subcatchment and assigns it to drainage system nodes for each time period		
TransportAnalyzer	Routes flows and pollutants through the drainage system over each time period		
ReportWriter	Writes formatted output report to file		
OutputFiler	Reads and writes intermediate results to scratch binary files	OutputReader OutputWriter	
Xerror	Exception class for tracking errors		

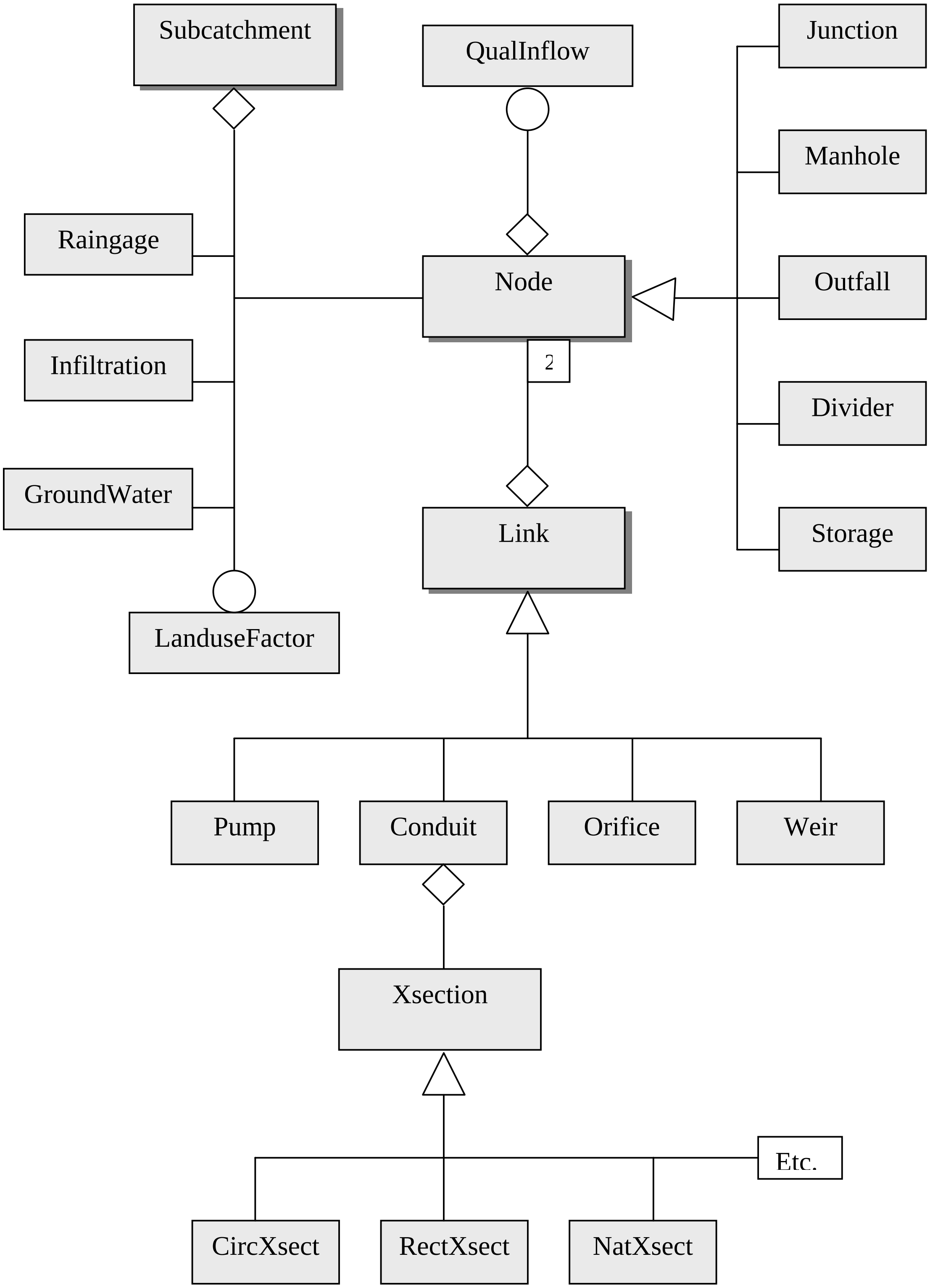

Figure A.1 Object Model Diagram of SWMM's Physical Classes

While Figure A.1 shows the relationships between physical objects in the drainage system, it does not provide any information on how the computation of runoff and pollutant loads is accomplished. This process is handled by the Project class, whose Object Model Diagram is shown in FigureA.3. It is the main class within SWMM that houses references to all of the data associated with a project as well as the overall flow of the computations. Only a single instance of this class is created for a run. The properties of this class consist of collections (lists) of the physical components (subcatchments, nodes, and links) that comprise the drainage area.

This class also utilizes a series of computational objects that perform the actual steps of a rainfall-runoff-routing simulation. These are:

- the InputReader class which reads in the project data
- the RainAnalyzer class which compiles relevant rainfall data and statistics for the simulation
- the RunoffAnalyzer class which computes runoff quantity and quality from the project's subcatchment areas
- the TransportAnalyzer class which routes flow and water quality constituents through the drainage network
- the ReportWriter class which writes a formatted report of computed results to a file.

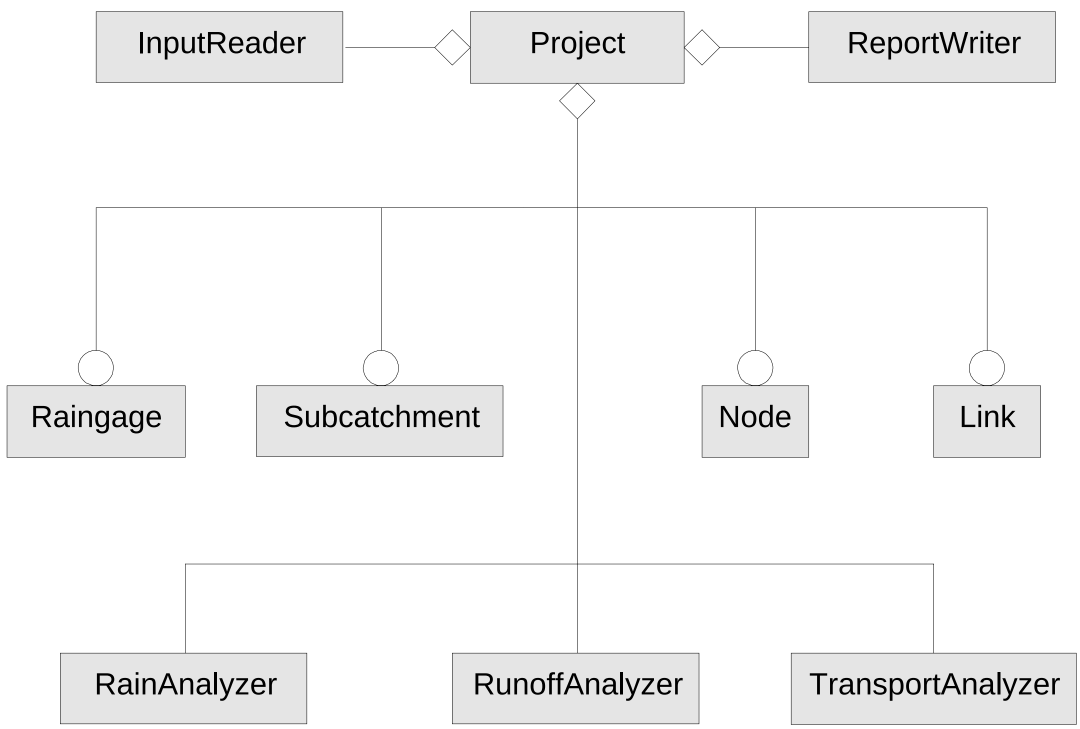

Table A. 2. Object Model Diagram of the Project Class